# Sound

## Mechanical, Longitudinal and Pressure Waves

# Sound is a Mechanical Wave

- Mechanical wave: a wave that requires a medium to transmit its energy
  - Example: Sound can not travel through a vacuum since there is no medium

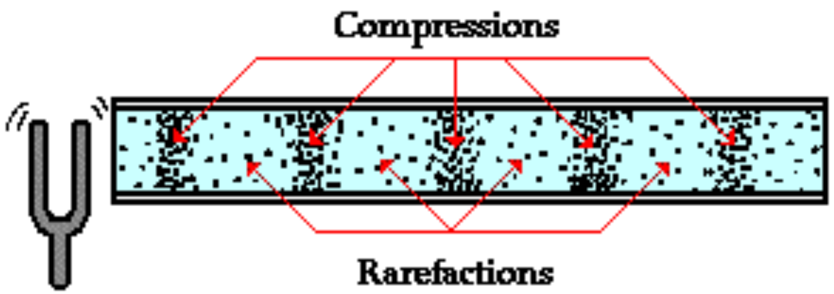
- A disturbance that is transported through a medium via the mechanism of particle-to-particle interaction, hence a mechanical wave

# Sound as a Longitudinal Wave

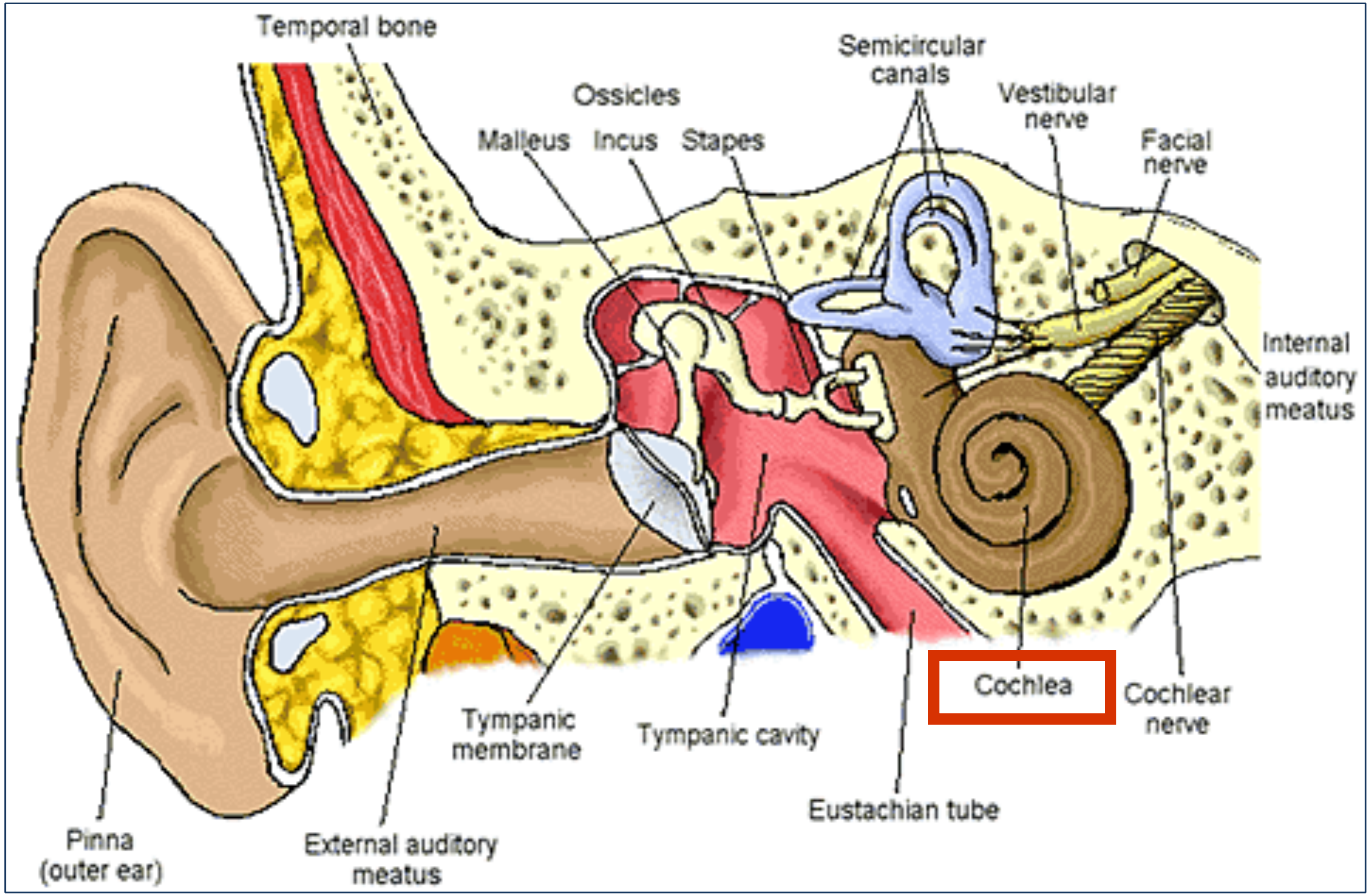
- Vibrations of particles in air are longitudinal
  - The motion of the particles of the medium is in a direction parallel (anti-parallel) to the direction of energy transport

# Sound as a Pressure Wave

- Compression and rarefaction are regions of high and low **pressure** within a sound wave

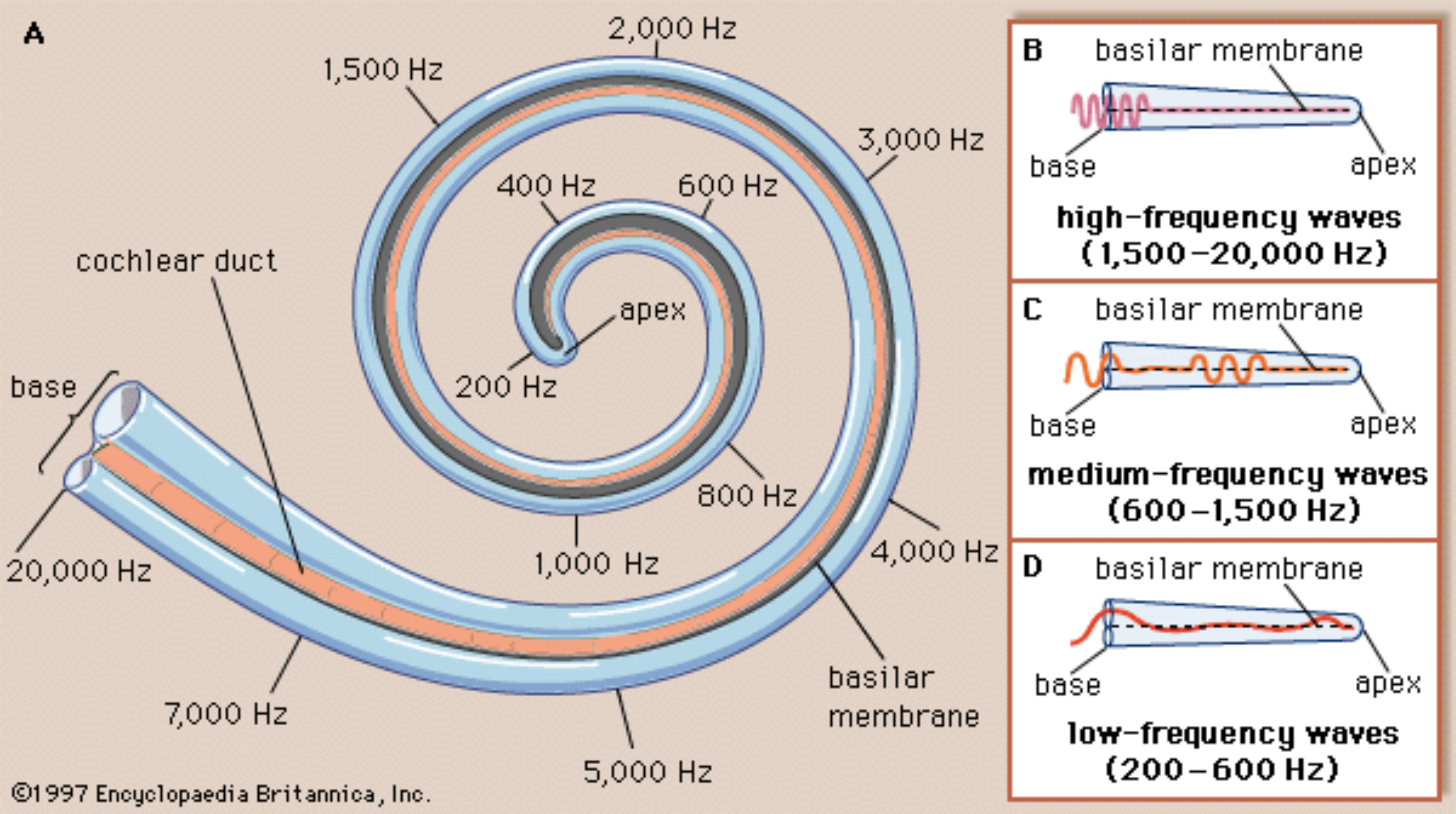


# How We Hear



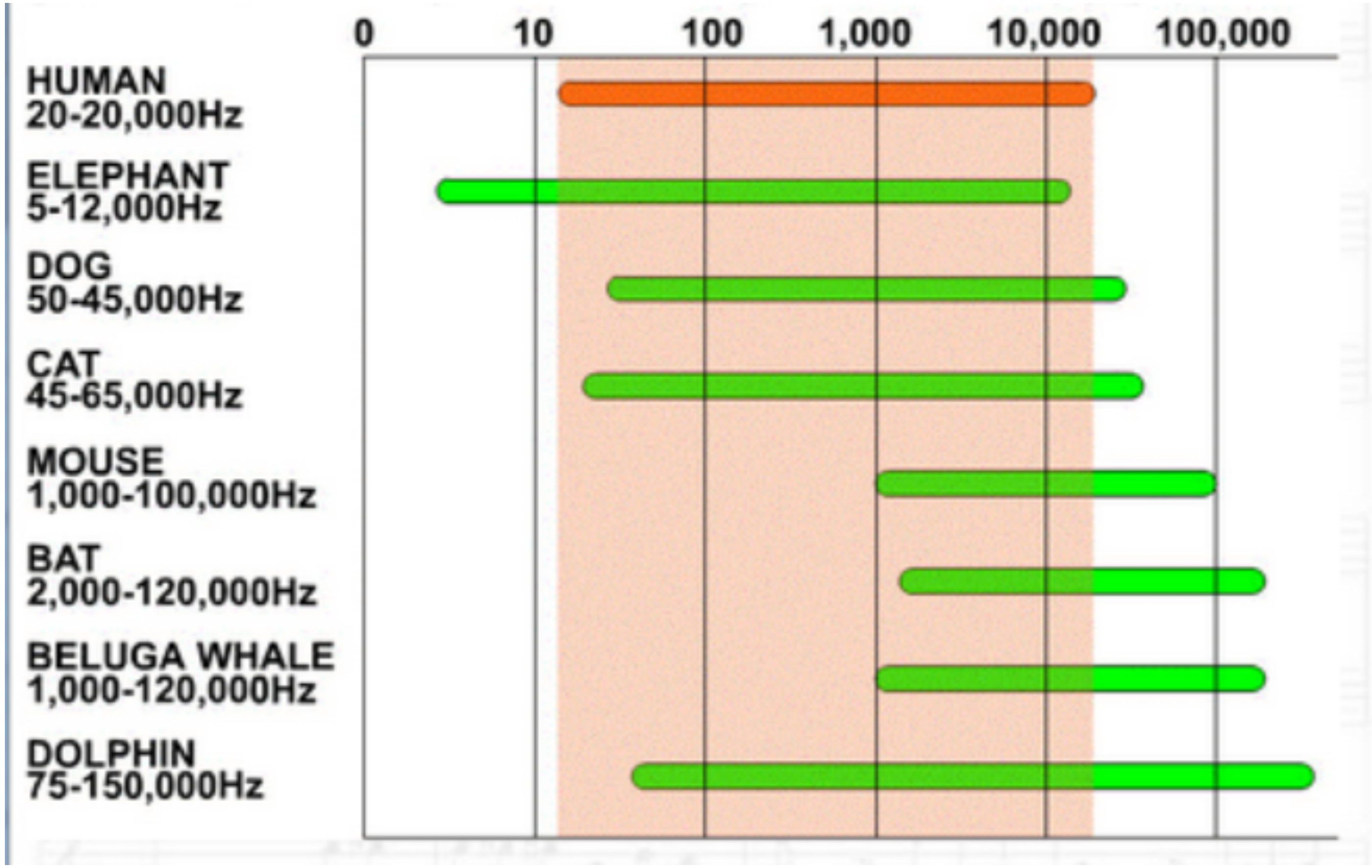
Temporal bone
Ossicles
Malleus
Incus
Stapes
Semicircular canals
Vestibular nerve
Facial nerve
Internal auditory meatus
Cochlea
Cochlear nerve
Eustachian tube
Tympanic cavity
Tympanic membrane
External auditory meatus
Pinna (outer ear)

# Cochlea



A
2,000 Hz
1,500 Hz
3,000 Hz
400 Hz
600 Hz
cochlear duct
apex
base
200 Hz
800 Hz
20,000 Hz
1,000 Hz
4,000 Hz
basilar membrane
7,000 Hz
5,000 Hz
©1997 Encyclopaedia Britannica, Inc.
B
basilar membrane
base
apex
high-frequency waves
(1,500–20,000 Hz)
C
basilar membrane
base
apex
medium-frequency waves
(600–1,500 Hz)
D
basilar membrane
base
apex
low-frequency waves
(200–600 Hz)

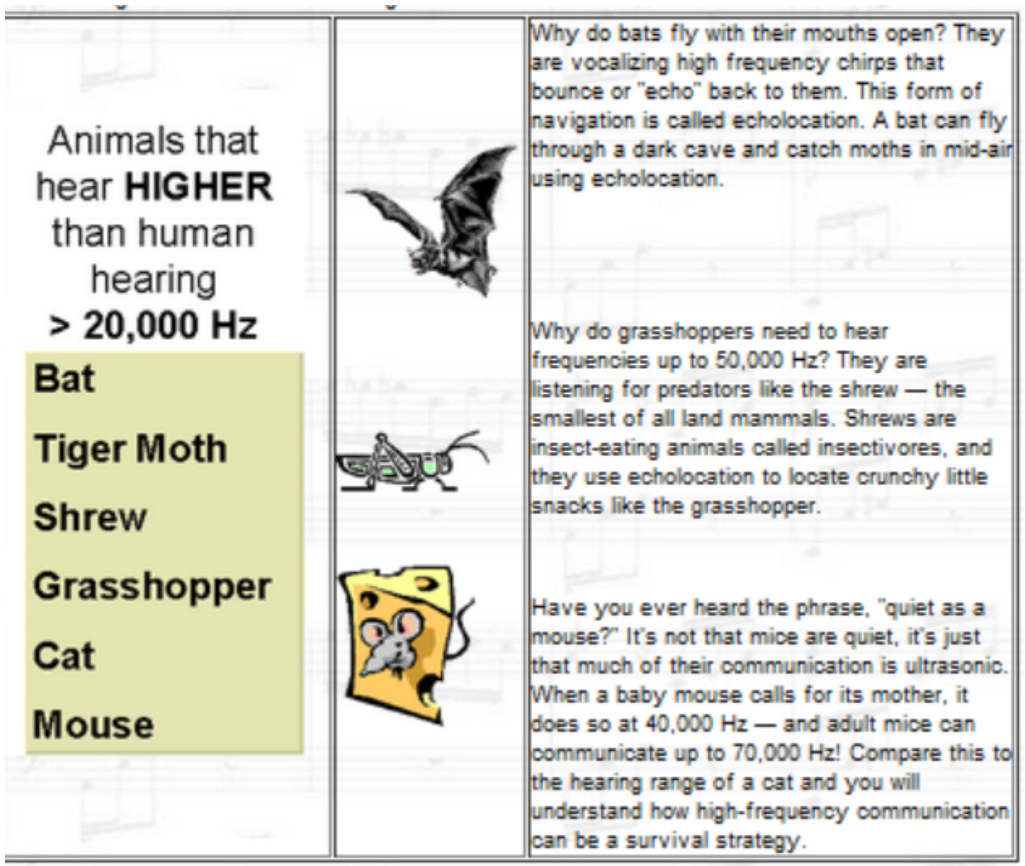
# Hearing Frequency Ranges



# Types of Sound Levels

- Ultrasonic: frequencies above human hearing
  - Examples: Bats and echolocation

- Infrasonic: frequencies below the level of human hearing
  - Examples: Elephants



# Intensity, Loudness & the Decibel Scale

- Intensity: amount of energy passing through a region in a given amount of time
  - Same as $\frac{Power}{Area}$ $units : \frac{W}{m^2}$
- Faintest sound detectable: 10^-12 W/m^2 (threshold of hearing, TOH)
  - Corresponds to a sound that will displace particles by one-billionth of a centimeter, 0.000000001 cm
- Most intense sound to safely detect is one billion times more intense than the TOH
- Decibel Scale: the loudness of sound
- Measured on a logarithmic scale
- Units: dB for decibel

Starting with zero at the threshold of normal hearing, an increase of each 10 dB means that sound intensity increases by a factor of 10.

- A sound of 10 dB is 10 times as intense as sound of 0 dB.
- 20 dB is not twice but 10 times as intense as 10 dB, or 100 times as intense as the threshold of hearing.
- A 60-dB sound is 100 times as intense as a 40-dB sound.

| Source | Intensity | Intensity Level | # of Times Greater Than TOH |
|---|---|---|---|
| Threshold of Hearing (TOH) | $1*10^{-12}$ W/m$^2$ | 0 dB | $10^0$ |
| Rustling Leaves | $1*10^{-11}$ W/m$^2$ | 10 dB | $10^1$ |
| Whisper | $1*10^{-10}$ W/m$^2$ | 20 dB | $10^2$ |
| Normal Conversation | $1*10^{-6}$ W/m$^2$ | 60 dB | $10^6$ |
| Busy Street Traffic | $1*10^{-5}$ W/m$^2$ | 70 dB | $10^7$ |
| Vacuum Cleaner | $1*10^{-4}$ W/m$^2$ | 80 dB | $10^8$ |
| Large Orchestra | $6.3*10^{-3}$ W/m$^2$ | 98 dB | $10^{9.8}$ |
| Walkman at Maximum Level | $1*10^{-2}$ W/m$^2$ | 100 dB | $10^{10}$ |
| Front Rows of Rock Concert | $1*10^{-1}$ W/m$^2$ | 110 dB | $10^{11}$ |
| Threshold of Pain | $1*10^{1}$ W/m$^2$ | 130 dB | $10^{13}$ |
| Military Jet Takeoff | $1*10^{2}$ W/m$^2$ | 140 dB | $10^{14}$ |
| Instant Perforation of Eardrum | $1*10^{4}$ W/m$^2$ | 160 dB | $10^{16}$ |

# Resonance

Resonance occurs whenever successive impulses are applied to a vibrating object in rhythm with its natural frequency.

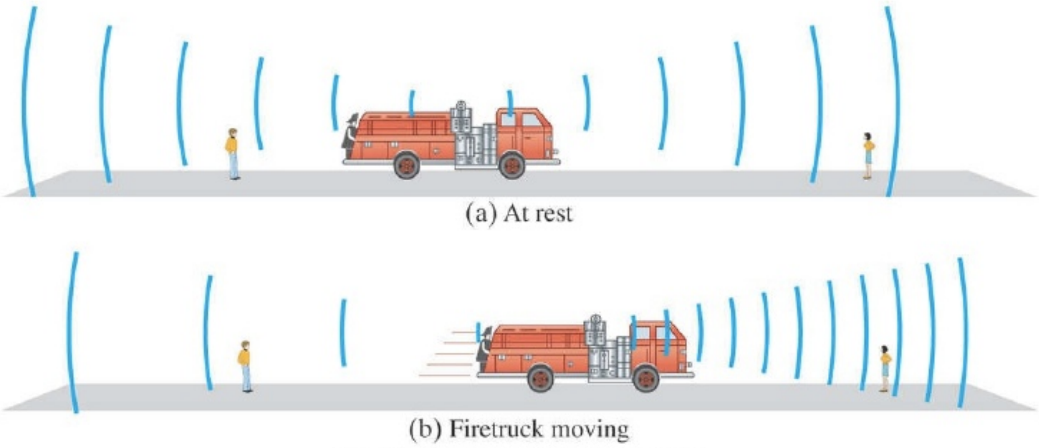
The Tacoma Narrows Bridge collapse was caused by resonance.

Wind produced a force that resonated with the natural frequency of the bridge.

Amplitude increased steadily over several hours until the bridge collapsed.

# Doppler Effect

- **Doppler Effect**: change in pitch due to a sound source moving towards or away from an observer



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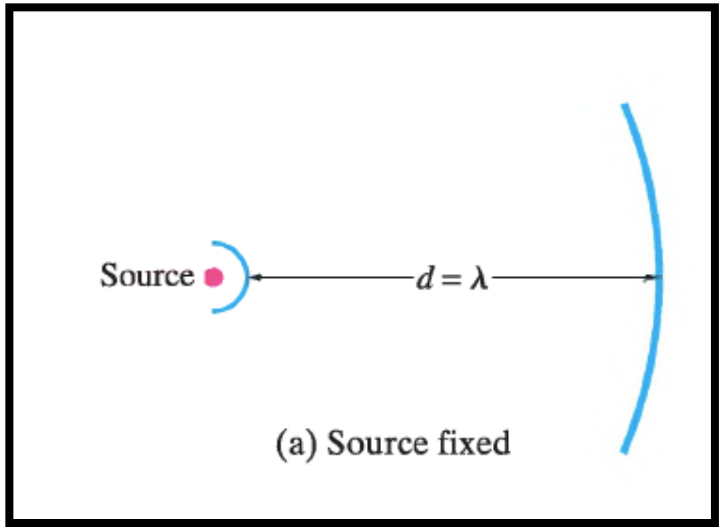
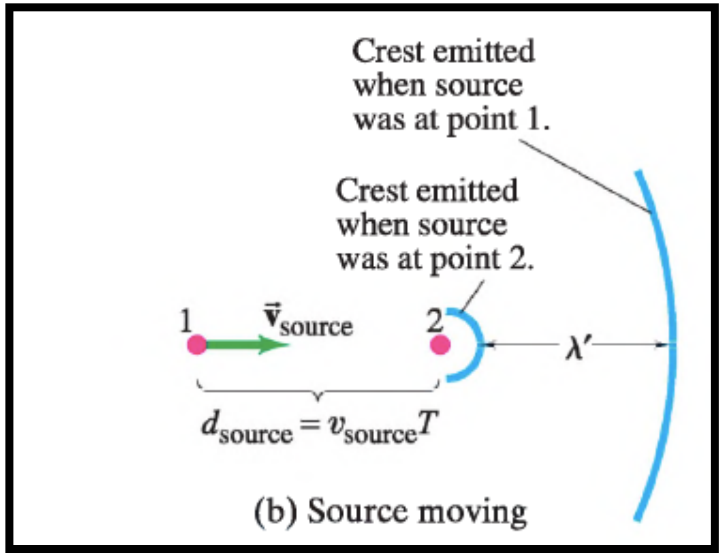


(a) Source fixed



(b) Source moving

# source moving **toward** stationary observer

- f’ = shifted frequency heard by observer
- f = original frequency
- v_source = speed of the sound source
- v_sound= speed of sound (340 m/s)

$$f' = \frac{f}{1 - \frac{v_{source}}{v_{sound}}}$$

# source moving **away** from stationary observer

$$f' = \frac{f}{1 + \frac{v_{source}}{v_{sound}}}$$

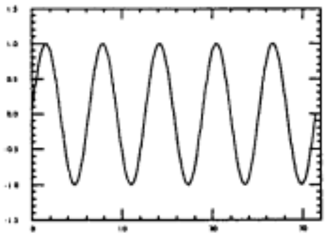
# Practice

- A police car is at rest and it’s siren is emitting at a frequency of 1600Hz. What frequency will you hear if you are at rest and the police car moves towards you at 25m/s?

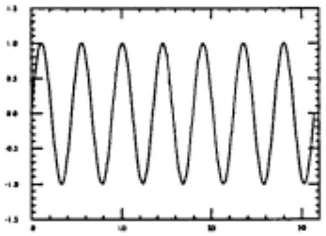
- What if the car moves away from you at the same speed?

Which of the following best represents the sound wave if the source is moving towards the observer?

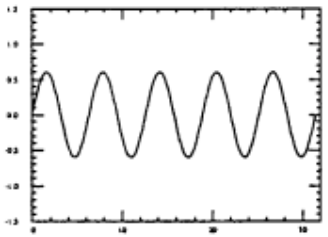
a.



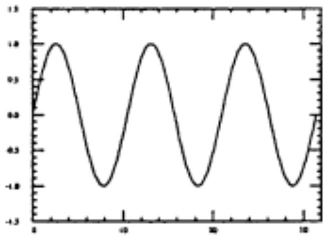
b.



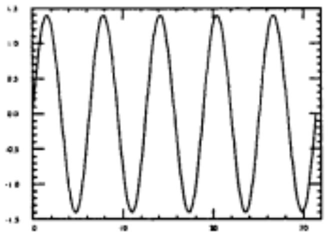
c.



d.

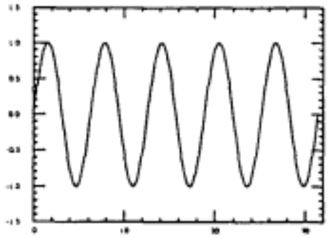


e.

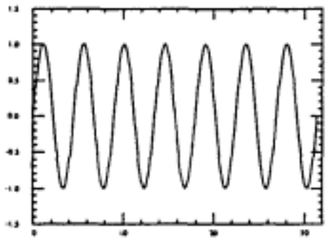


Which of the following best represents the sound wave if the source is moving away from the observer?

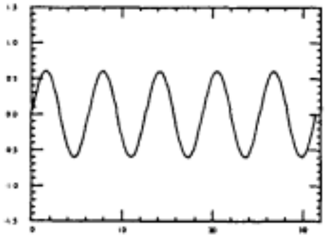
a.



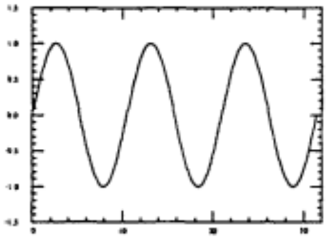
b.



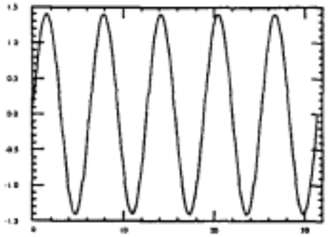
c.



d.



e.



# observer moving **toward** stationary source

$$f' = f(1 + \frac{v_{obs}}{v_{sound}})$$

**HONORS ONLY**

# observer moving **away** from stationary source

$$f' = f(1 - \frac{v_{obs}}{v_{sound}})$$

**HONORS ONLY**